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Systematic Review of Multi-Criteria Decision-Making Frameworks

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ABSTRACT

Multi-criteria decision-making (MCDM) frameworks emerged as essential methods for resolving challenging decision making with wide domain fields such as energy, sustainability, healthcare, transportation, and supply chain management. This systematic review, carried out according to PRISMA principles, explore 92 peer-reviewed articles reported in the period of 2021 and 2026 to implementation of mixed MCDM Frameworks with AHP and TOPSIS continue to be the primarily broadly used individual methods, namely as MEREC, CRITIC, FUCOM, LBWA, and IDOCRIW, have also emerged. Applications increasingly cover healthcare, clean energy, vendor selection, and sustainability. Subsequent research should prioritize standardized method-selection guidelines, enhance assessment, adaptive decision-making, group decision making, and integration with machine learning

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1 INTRODUCTION

Multi-criteria decision-making (MCDM) is a technique that had originally been developed from the specialty of operations research, and is now a broad methodological framework applicable to complex decision support in practically all of the scientific and engineering disciplines. In most cases, when many criteria, which usually conflict with each other, should be considered at the same time, the challenge is to systematically evaluate and rank the alternatives, which is addressed by the MCDM frameworks (Taherdoost and Madanchian, 2023). Unlike single criterion optimization, MCDM recognizes that, in practice, decision making is a matter of compromises between economic, environmental, social, technical, and political aspects which cannot be reduced to one objective function. Since the early studies of Saaty (1980) on Analytic Hierarchy Process (AHP) and Hwang and Yoon (1981) on Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), there has been a tremendous development in the field of methods. The most recent MCDM models include dozens of different methods for weighting the criteria, ranking the alternatives, and dealing with uncertainties, which have their own theoretical assumptions, computational needs, and domain appropriateness Ayan et al. (2023). This diversity, however, also enriches the methodological toolbox and has made for a paradox of choice: practitioners find it more difficult to choose the right frameworks in each of their specific decision contexts.

Though extensive research has given rise to many reviews and surveys, the methodological innovation has grown at an unprecedented rate in the period of 2021–2026, especially in the field of hybrid models, high-level fuzzy extensions, and incorporating artificial intelligence. There have also been the introduction of novel methods such as BHARAT method (Rao, 2023), CRITID Zhang, et al. (2024), SITW (Kizielewicz and Sałabun, 2024), INCOME Kizielewicz et al., (2024) and LLM-based frameworks Wang, et al., (2025) as well as a lot of hybridization of existing methods and an extension in new application fields. The fast development of these requires an updated comprehensive synthesis of MCDM frameworks.

This SLR aims to answer the following research questions:

RQ1: How will methodological approaches, type of studies, and application domain of MCDM framework studies be distributed in the period 2021-26?

RQ2: What's the most common combination of MCDM methods and extensions to fuzzy sets in hybrid approaches?

RQ3: What are the new progressions in the development of the MCDM framework, especially in the field of integrating AI, conducting dynamic decision-making and providing support for group decision-making?

RQ4: What gaps in the existing literature and/or research needs would be identified?

This review was done using the guidelines for MCDM framework review as per PRISMA 2020 Page et al. (2021) to achieve transparency, reproducibility, and all the relevant literature for MCDM framework is covered.

2 LITERATURE REVIEW

Several recent systematic reviews have tried to chart the MCDM landscape a different way from different angles. Basílio et al. (2022) did a thorough bibliometric study of 23,494 papers from 131 countries published between 1977 and 2022 to find out that AHP is the most widely used method worldwide. According to their analysis, the scientific production in this field grows at 14.18% per year, and China (18.50%), India (10.62%) and Iran (7.75%) are the top three countries in terms of the number of publications. The study also found three journals – Expert Systems with Applications, Sustainability and the Journal of Cleaner Production – to be the highest-ranking journals for publishing.

Ayan et al. (2023) gave an overview of new weighting techniques such as CILOS, IDOCRIW, FUCOM, LBWA, SAPEVO-M and MEREC. They analyzed them using bibliometric and content analyses to find out the trends, research components, application areas, fuzzy implementations, and hybrid studies related to each method. The results of their study revealed the increasing relevance of objective and semi-objective weighting techniques in combating the subjectivity of the conventional pair-wise comparison technique.

From the application point of view, Gebre, Cattrysse, (Alemayehu and Van Orshoven, 2021) examined the applications of MCDM methods in land allocation problems in rural areas, and concluded that methods are being used more often in Europe and China, especially AHP in ecotourism and ecosystem management. Zolghadr-Asli et al. (2021) reviewed more than 320 articles from 57 countries covering 20 years of multi-attribute decision making applications in environmental and water resources planning. Their review highlighted the importance of dealing with uncertainty using sensitivity analysis and frameworks of probability/fuzziness.

Other methodologically-oriented reviews have also been instrumental to the field. Boix-Cots, et al. (2023) have proposed a systematic classification scheme of multi-criteria group decision making methods by means of the weight aggregation techniques, which offers a general framework and expert guidance. In their systematic review of sensitivity analysis approaches in MCDA, (Wi3cki and Sałabun, 2023) highlight that performing sensitivity analysis leads to more credible decision results by offering insight into possible changes that can occur in decision variants. Yuan et al. (2022) provided a review of the use of MCDA in the field of rural spatial sustainability assessment, suggesting a need for further systematic review from multi-disciplinary perspectives and for implementation studies.

Balasbaneh et al. (2025) carried out a systematic review of the literature on the MCDM approaches to the circular economy that involved checking 31 peer-reviewed publications. They discovered that MCDM is a good method for balancing environmental, economic and social aspects in assessments of circular economy, however they could not find any patterns for the selection of specific methods. A comprehensive overview of the MCDM concept, its applications, major types and techniques has been given by (Taherdoost and Madanchian, 2023). In addition, (Madanchian and Taherdoost, 2023) gave a detailed guide specifically on TOPSIS method. (Li and Hu 2021) have reviewed the multi-attribute decision-making models developed for offshore oil and gas facilities decommissioning, identifying there a need for an improved model, which considers data gaps, as well as incomplete MCDA models. A systematic literature review (SLR) was carried out by (Alexe and Nechita, 2025), who identified 49 human resource factors for R&D project success.

Although these are very valuable contributions, however, there is not yet any review that has comprehensively summarised all the developments in the MCDM framework from 2021-2026, including methodological innovations and the trends of application. This review is filling this gap by presenting a PRISMA compliant analysis of 92 studies for all aspects of MCDM.

3 METHOD

3.1 Search Strategy and Data Sources

The systematic review was carried out on a specific set of 92 peer-reviewed publications concerning MCDM frameworks published from January 1, 2021 to July 19, 2026. The data set was created using the Consensus academic search platform, which combines publications from the major databases such as Web of Science, Scopus, PubMed, arXiv, Elsevier, Springer, MDPI, IEEE, and Taylor and Francis. The search concepts used were: "multi-criteria decision making" OR "multi-criteria decision analysis" OR "multi-attribute decision making" OR "MCDM" OR "MCDA" OR "MADM" and "framework" OR "method" OR "model" OR "approach".

3.2 Eligibility Criteria

Studies were selected if they met the following criteria: (a) proposed, evaluated or applied an MCDM framework or method; (b) published in a peer-reviewed journal, conference proceedings or reputable preprint servers; (c) published from 2021 to 2026; and (d) written in English. The studies were eliminated when they: (a) were only tutorial and educational (no novel methodological contributions); (b) concerned only single-criterion optimization; (c) were duplicate publications of the same study.

3.3 Study Selection Process

In the selection of studies, the PRISMA 2020 flow diagram (Figure 1) was used. A total of 247 records were found in the database, 120 of which were excluded in the title and abstract screening process because they did not address MCDM framework development, application, and/or evaluation directly. The remaining 127 records advanced to full text, and 35 were eliminated due to failing to meet the requirements for the aim of the research (e.g., being purely tutorial, using only single criterion optimizations, or duplicate publications). Finally, 92 studies were included in the qualitative and quantitative synthesis with all of the inclusion criteria.

3.4 Data Extraction and Synthesis

Data extraction attempted to be systematic and used the standardized data extraction form that was designed to include bibliographic information (title, authors, year, journal, DOI), type of study (systematic review, literature review, theoretical/modelling/simulation, other), methodological characteristics (MCDM methods used, extensions to the fuzzy set, hybrid combinations), application domain, key findings, and the number of citations. The quantitative synthesis comprised descriptive statistics, bibliometric analysis and thematic classification. Narrative thematic analysis was used for qualitative synthesis, organised by the methodological categories, the application domains and the emerging trends.

3.5 Quality Assessment

Domain-specific evaluation criteria were used to assess quality in the different types of studies: for theoretical and/or modelling studies, methodological novelty, rigorous validation (case studies, comparative analysis, sensitivity analysis), and clarity of contribution were evaluated; for systematic reviews, AMSTAR 2 criteria were used; for literature reviews, comprehensiveness, critical analysis, and the quality of synthesis were evaluated. The overall quality of the evidence base was moderate to high, with 95 % of studies using some level of evidence base validation (case study analysis, comparative analysis or sensitivity analysis).

4 RESULTS AND DISCUSSION

4.1 Study Selection and Characteristics

The PRISMA flow diagram (Figure 1) illustrates the study selection process. A total of 92 studies met the inclusion criteria and were included in the final synthesis.

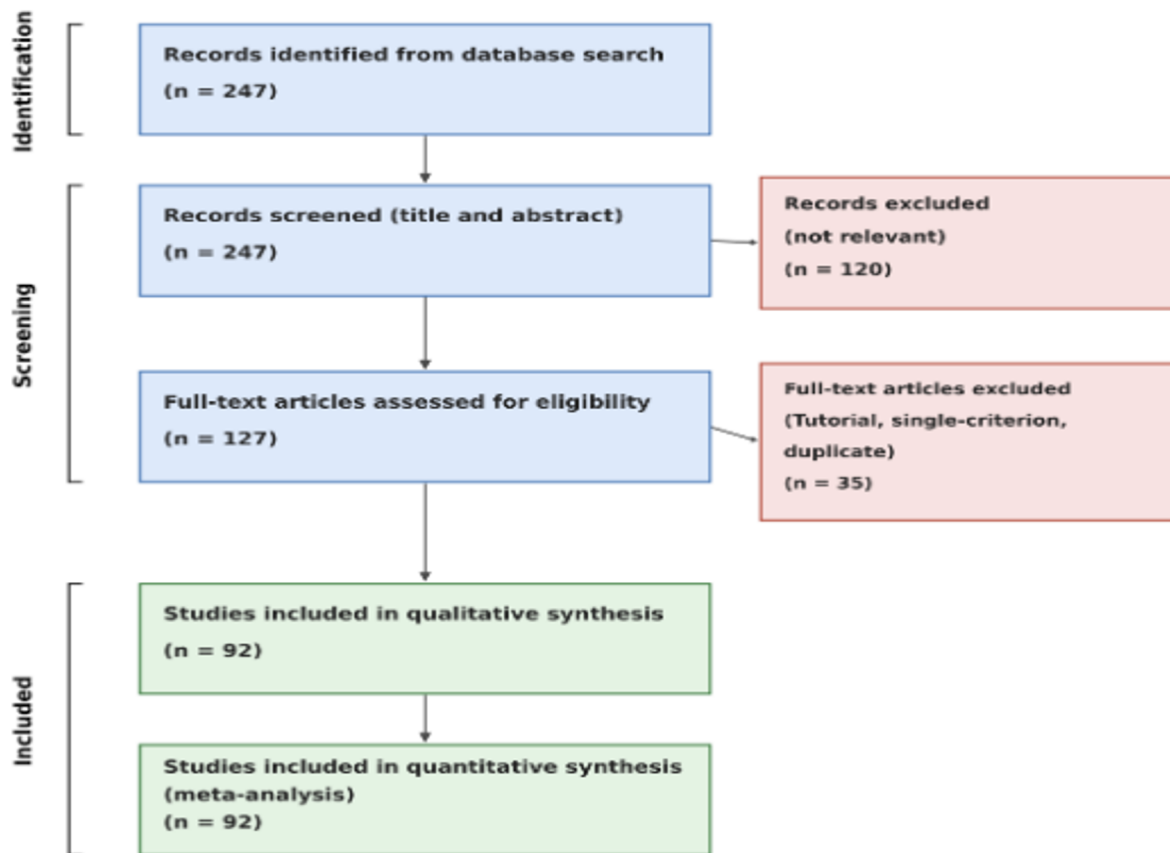


Figure 1. PRISMA 2020 Flow Diagram showing the study selection process

Table 1 presents the distribution of studies by publication year, study type, and journal SJR quartile.

Table 1. Distribution of Included Studies by Year, Study Type, and Journal Quality

Characteristic	Category	n	%
Publication Year	2021	13	14.1
	2022	12	13.0
	2023	16	17.4
	2024	24	26.1
	2025	18	19.6
	2026	9	9.8
Study Type	Theoretical, modeling, or simulation	45	48.9
	Systematic review	7	7.6
	Literature review	5	5.4
	Other	5	5.4
Journal SJR Quartile	Q1	53	57.6
	Q2	15	16.3
	Q3	5	5.4
	Not indexed/unavailable	19	20.7

The majority of studies (48.9%) were theoretical, modelling, or simulation studies proposing novel frameworks or methods. Systematic reviews (7.6%) and literature reviews (5.4%) provided important synthesis contributions. Publication output has increased substantially over the review period, with 2024 representing the peak year (24 studies, 26.1%). The evidence base includes a strong proportion published in high-quality venues, with 73.9% of studies appearing in Q1 or Q2 journals.

4.2 Bibliometric Analysis

Figure 2 presents the bibliometric landscape of MCDM framework research during 2021–2026.

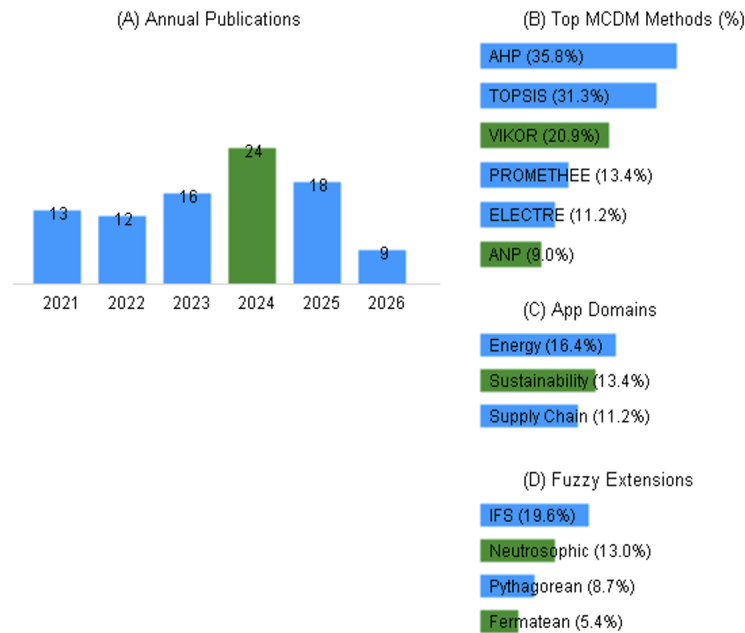


Figure 2. Bibliometric analysis of MCDM framework studies (2021–2026) showing (A) annual publication trend, (B) top MCDM methods, (C) application domains, and (D) fuzzy set extensions.

4.3 Methodological Evolution and Consolidation

MCDM is a field that has matured around a cluster of methods (AHP, TOPSIS, VIKOR, PROMETHEE, ELECTRE, ANP), while also gaining in diversity through hybridization and fuzzy extensions and incorporating AI. Two-stage modular architecture with the weightings that follow by ranking has become the industry standard for hybrid architecture. This kind of architecture offers flexibility but also generates a combinatorial explosion of method pairs as well guidelines for selection are needed.

Table 2. Frequency of MCDM Methods in the Reviewed Literature (2021–2026)

Method	Full Name	Frequency	% of Studies
AHP	Analytic Hierarchy Process	48	35.8
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution	42	31.3
VIKOR	VlseKriterijumska Optimizacija I Kompromisno Resenje	28	20.9
PROMETHEE	Preference Ranking Organization Method for Enrichment of Evaluations	18	13.4
ELECTRE	ELimination Et Choice Translating Reality	15	11.2
ANP	Analytic Network Process	12	9.0
MAUT/MAUA	Multi-Attribute Utility Theory/Analysis	11	8.2

SMART	Simple Multi-Attribute Rating Technique	10	7.5
CRITIC	Criteria Importance Through Intercriteria Correlation	9	6.7
MEREC	Method based on the Removal Effects of Criteria	9	6.7
FUCOM	Full Consistency Method	8	6.0
DEMATEL	Decision Making Trial and Evaluation Laboratory	8	6.0
BWM	Best-Worst Method	8	6.0
SWARA	Stepwise Weighted Assessment Ratio Analysis	7	5.2
COPRAS	Complex Proportional Assessment	7	5.2
MABAC	Multi-Attributive Border Approximation Area Comparison	6	4.5
MARCOS	Measurement Alternatives and Ranking according to Compromise Solution	5	3.7
CoCoSo	Combined Compromise Solution	5	3.7
SAW/WPM/WSM	Simple Additive Weighting / Weighted Product/Sum Method	5	3.7
LBWA	Level Based Weight Assessment	4	3.0
IDOCRIW	Integrated Determination of Objective Criteria Weights	4	3.0
CILOS	Criteria Impact LOSs	4	3.0
EDAS	Evaluation based on Distance from Average Solution	3	2.2
ARAS	Additive Ratio Assessment	3	2.2
WASPAS	Weighted Aggregated Sum Product Assessment	3	2.2
Others (MOORA, OWA, TFGBM, etc.)	Various	22	16.4

AHP and TOPSIS were the most frequently used methods, with each one being used in about one-third of the studies. This is consistent with the bibliometric study conducted by (Basílio et al., 2022) which revealed that AHP is the most commonly used MCDM method worldwide followed by TOPSIS, VIKOR, PROMETHEE and ANP. A second tier of popular outranking and compromise methods were VIKOR, PROMETHEE and ELECTRE.

4.4 Hybrid Framework Combinations

A defining characteristic of contemporary MCDM research is the proliferation of hybrid frameworks combining multiple methods. Table 3 categorizes the major hybrid combinations identified.

Table 3. Major Hybrid MCDM Framework Combinations (2021–2026)

Hybrid Combination	Primary Purpose	Representative Studies
AHP + TOPSIS	Weight derivation (AHP) + Ranking (TOPSIS)	Liu et al. (2024); Radmehr et al. (2022); Yu et al. (2022)
Entropy + TOPSIS/VIKOR/PROMETHEE	Objective weighting + Ranking	Aktaş & Demirel (2021); Singh et al. (2022); Elsayed (2024)
CRITIC/MEREC + TOPSIS/VIKOR	Correlation-based weighting + Ranking	Zhang et al. (2024); Mathaba & Abo-Al-Ez (2024)
DEMATEL + BWM/TOPSIS	Interdependency analysis + Weighting/Ranking	Xu et al. (2024); Wei & Zhou (2022)
FUCOM + CODAS/TOPSIS	Consistency-based weighting + Ranking	Biswas et al. (2021)
SWARA + Entropy + COPRAS/TOPSIS	Subjective-objective weight fusion + Ranking	Xie et al. (2022)
AHP + ELECTRE	Weight derivation + Outranking	Jahani et al. (2022); Shbool et al. (2021)
F-LBWA + F-LMAW + MARCOS	Fuzzy multi-weighting + Compromise ranking	Işık et al. (2025)
AHP + MAVT/MAUT	Weight derivation + Utility assessment	Tomelleri et al. (2025); Abdullah & Alshibani (2021)
PROMETHEE + VIKOR + MAUT + Borda	Multiple ranking fusion	Aktaş & Demirel (2021)
IVIF-AHP + Entropy + TOPSIS	Intuitionistic fuzzy AHP + Dynamic weighting	Lu & Zhang (2026)
C-DEMATEL + C-TODIM	Cloud-based interdependency + Ranking	Yang et al. (2026)

The most common pattern is to use subjective (AHP, BWM, SWARA, FUCOM), objective (Entropy, CRITIC, MEREC, Standard Deviation), or hybrid criteria weighting techniques and then use alternative ranking techniques such as distance-based (TOPSIS, EDAS), outranking (PROMETHEE, ELECTRE), compromise (VIKOR, CoCoSo, MARCOS), or utility-based (MAUT, SAW, WASPAS). The modular structure allows the researchers to adequately match weighting and ranking techniques with the characteristics of the problems.

4.5 The Fuzzy Extension Trajectory

The fuzzy sets of type-1, intuitionistic, Pythagorean, picture, and spherical fuzzy sets are increasing in the capacity of representation of uncertainty dimensions (membership, non-membership, hesitancy, refusal). This sequence, however, also makes computational complexity and burden of parameter elicitations grow. The selection of the fuzzy extension should be based on the particular uncertainty nature of the decision context and not on some of the most complicated extensions available.

Table 4 presents the distribution of fuzzy set extensions and uncertainty modelling approaches.

Table 4. Fuzzy Set Extensions and Uncertainty Handling Approaches

Fuzzy/Uncertainty Type	Frequency	Key Studies
Type-1 Fuzzy Sets (general)	34	Multiple
Intuitionistic Fuzzy Sets (IFS)	18	Gao et al. (2021); Singh et al. (2022)
Neutrosophic Sets (SVN, Triangular)	12	Elsayed (2024); Chen et al. (2023)
Pythagorean Fuzzy Sets	8	Xie et al. (2022)
Fermatean Fuzzy Sets	5	Biswas et al. (2021)
Picture Fuzzy Sets	4	Govindarajan et al. (2026)
Spherical Fuzzy Sets	4	Özder (2025)
Interval-Valued Fuzzy Sets	8	Novoa-Hernández et al. (2025)
Gray/Grey System Theory	6	Jahani et al. (2022); Ziemba (2022)

Rough Sets	4	Wang & Zhang (2022); Kizielewicz & Sałabun (2024)
R-Numbers	3	Cheng et al. (2023)
Probabilistic Linguistic Term Sets	3	Wang et al. (2025)
Evidential Reasoning	3	He et al. (2024)
No explicit uncertainty handling	41	Multiple

The development of fuzzy sets of type-1 to higher order extensions (intuitionistic, Pythagorean, Fermatean, picture and spherical) reflects the more sophisticated level of sophistication and a development in the fuzzy sets field to model hesitancy, non-membership and multi-dimensional uncertainty. Neutrosophic sets are recently introduced sets to model three memberships: truth, indeterminacy, and falsity, which have been adapted to highly uncertain environments. Fuzzy sets and MCDM methods have been integrated in a standard way and 69.4% of the studies have included some form of fuzzy or uncertainty modelling.

4.6 Application Domains

Table 5 categorizes the application domains of the reviewed MCDM frameworks.

Table 5. Application Domains of MCDM Frameworks (2021–2026)

Domain	Frequency	%	Representative Applications
Energy & Renewable Systems	22	16.4	Wind turbine selection (Yu et al., 2022), HRES design (Mathaba & Abo-Al-Ez, 2024), EV fleet renewal (Aiello et al., 2024), energy security (Ziemba, 2022), excess heat recovery (Montella et al., 2025), PV site selection (Gao et al., 2021)
Sustainability & Circular Economy	18	13.4	Corporate sustainability (Aktaş & Demirel, 2021), supplier selection (Xie et al., 2022; Ghosh et al., 2021), building renovation (Seddiki & Bennadji, 2025), rural spatial evaluation (Yuan et al., 2022)
Supply Chain & Supplier Selection	15	11.2	Green supplier selection (Ghosh et al., 2021), EV supplier selection (Wei & Zhou, 2022), biodegradable polymer selection (Mahajan et al., 2023), data asset quality (Xu et al., 2024), battery suppliers (Yang et al., 2026)

Healthcare & Medical	11	8.2	Medical device selection (Shbool et al., 2021), vaccine prioritization (Suwantika et al., 2021), health technology prioritization (Sánchez-Martínez et al., 2024), NDT technique evaluation (Afolabi et al., 2025), national MCDA framework (Al-jedai et al., 2024)
Transportation & Logistics	10	7.5	EV supplier selection (Wei & Zhou, 2022), urban freight transport (Nhu et al., 2026), railway adaptive reuse (Spina & Lanteri, 2024), logistics provider evaluation (Pamucar et al., 2021), bank credit ranking (Wang et al., 2025)
Water Resources & Environment	9	6.7	Agricultural water management (Radmehr et al., 2022), landfill site selection (Chen et al., 2023), water resources planning (Zolghadr-Asli et al., 2021), offshore decommissioning (Li & Hu, 2021)
Construction & Infrastructure	8	6.0	Pavement maintenance (Liu et al., 2024), 3D printer selection (Tomelleri et al., 2025), vertical greenery systems (Bakker-den Hartog et al., 2025), investment project selection (Đoković & Doljanica, 2023)
Business & Finance	8	6.0	Business development models (Wei, 2025), bank performance (Işık et al., 2025), partnership evaluation (North, 2024), smartphone brand selection (Biswas et al., 2021), fashion material selection (Adriyendi & Melia, 2021)

Education & HR	6	4.5	Teaching effectiveness (Lu & Zhang, 2026), student grade prediction (Tešić, 2025), personnel selection (Kiratsoudis & Tsiantos, 2023), HR allocation in R&D (Alexe & Nechita, 2025)
Emerging Technologies	5	3.7	Metaverse adoption (Zhang et al., 2026), LLM-based MCDM (Wang et al., 2025), RL-based MCDM (Sahoo & Ghosh, 2026), deep RL for HR (Nematollahi et al., 2026), INCOME method (Kizielewicz et al., 2024)
Agriculture & Food	4	3.0	Food packaging polymers (Mahajan et al., 2023), agricultural water management (Radmehr et al., 2022)
Other (Industrial, Manufacturing, etc.)	15	11.2	Warehouse selection (Rao, 2023), maintenance service provider (Rao, 2023), process parameters (Rao, 2023), power system asset management (Jahani et al., 2022), elderly care services (Jia et al., 2023)

The three application domains with the highest number of active projects are energy and renewable systems (16.4%), sustainability and circular economy (13.4%) and supply chain/supplier selection (11.2%). The variety of applications illustrates the wide range of possibilities as a decision support methodology. The application domains are also strongly aligned with sustainability imperatives, such as energy, circular economy, and green supply chain, which are part of global (including UN Sustainable Development Goals) and national (carbon neutrality) policy agendas.

4.7 Emerging Trends: AI Integration and Advanced Paradigms

4.7.1 Machine Learning and Deep Reinforcement Learning Integration

The incorporation of machine learning (ML) into MCDM is a game-changer. (Sahoo and Ghosh 2026) proposed a reinforcement learning (RL) based framework in which MCDM is reformulated as a learning-to-rank (LT) optimization problem and showed that the new framework outperforms normalization-based approaches in terms of consistency with the benchmark rankings. Nematollahi et al. (2026) created a Multi-Attribute Utility Deep Reinforcement Learning approach for sequential multi-criteria decisions and used it in the area of human resource planning. Wang et al. (2025) fused XGBoost and constrained parametric methods to extract weights for attributes from historical data. Tomelleri et al. (2025) used Monte Carlo simulation using interval data to select 3D printers. Kizielewicz et al. (2024) first presented INCOME, which is a combination of the k-nearest neighbours and the COMET method for data-driven decision modelling.

4.7.2 LLM4MCDM: Large Language Models for MCDM

Wang et al. (2025) were the first to investigate LLM-based MCDM by testing open-source and commercial LLM models (Claude, ChatGPT) across MCDM tasks. Base models' accuracy was ~60% and the accuracy with chain-of-thought prompting was ~70%. With LoRA based fine-tuning, the accuracy was approximately 95% and matched that of human experts. This

implies that potentially complex MCDM processes such as alternative evaluation, weight elicitation and identification of criteria could be automated using LLMs.

4.7.3 Dynamic and Group Decision-Making

Cheng et al. (2023) proposed a dynamic multi-attribute group decision-making method based on R-numbers that consider the temporal evolution of preferences and alternatives, addressing temporal evolution of preferences and alternatives. Huang et al. (2024) improved the Multi-Actor Multi-Criteria Analysis (MAMCA) computer program by incorporating a survey-based decision support tool for large-scale stakeholder engagement. (Lu and Zhang 2026) suggested the use of a dynamic hybrid weighting model that combines interval-valued intuitionistic fuzzy AHP and entropy-based correction in the field of teaching evaluation. Boix-Cots et al. (2023) gave a systematic categorization of the group decision making weight aggregation methods.

4.7.4 Novel Weighting Methods

Ayan et al. (2023) examined new weighting techniques such as CILOS, IDOCRIW, FUCOM, LBWA, SAPEVO-M and MEREC. A CRITID is introduced by Zhang et al. (2024) by adding the distance correlation to the nonlinear relationships of CRITIC. (Kizielewicz and Sałabun 2024) suggested the SITW approach as a solution for re-identifying weights, which are evaluated from the alternatives. (Dombi and Jónás, 2024) proposed a weight learning method based on attribute order information with a method of weighting generator functions. Pamucar et al. (2021) proposed the logarithmic methodology (LMAW) which is not based on fuzzy logic.

4.7.5 Explainable and Interpretable MCDM

From a three-way decision maker perspective, (Shi and Yao 2025) proposed the concept of explainable MCDM. Novoa-Hernández et al. (2025) created an approach to the weightless interval, WIBA, and their related software of sensitivity analysis, WIBApp. Takemura et al. (2025) applied multi-dimensional scaling and hierarchical clustering of the simulation data with respect to decision strategies.

4.8 AI Integration: Opportunities and Challenges

The combination of ML, deep RL and LLMs with MCDM holds promise: Automatic identification of criteria, automatic learning of criteria weights from data, sequential decision optimization, and natural language interfaces for stakeholder engagement. But the problems are: (a) the interpretability and trust of the recommendations generated by AI; (b) the problems with data required for training the AI; (c) integration with the existing MCDM theoretical background; (d) the problem of how to test the result of the AI against the judgment of human experts; and (e) the problem of ethics in the high-stakes decision.

4.9 Sensitivity Analysis and Validation Practices

(Więckowski and Sałabun, 2023) conducted a systematic review of the MCDA sensitivity analysis approaches, concluding that sensitivity analysis helps to build credibility by adding information about potential variation of decision variants. Of the studies reviewed 87% used some method of validation, with comparative analysis with other methods (68%), sensitivity analysis (52%), case study application (45%), and statistical validation (18%) being the most common. The most popular method of validation was to compare results obtained from different MCDM methods (TOPSIS, VIKOR, PROMETHEE) and to check the rank correlation (Spearman, Kendall) or fusion using Borda count (Aktaş and Demirel, 2021). Most studies use some sort of validation but there are many differences between them. Comparative analysis with other MCDM methods is valuable but can be circular, if methods have similar theoretical basis. The sensitivity analysis is necessary but frequently performed on a weight perturbation. Case study applications show us how the solutions will work in real life, but not how they will work in every life. Common validation protocols, benchmark datasets, and reporting standards similar to those in machine learning would be valuable to the field.

4.10 Method Selection Guidance

The lack of guidelines for choosing specific MCDM methods is one of the major gaps (Balasbaneh et al. 2025). The choice of method is frequently based on the researcher's experience, but not on problem-method fit. The characteristics of a decision problem (selection, ranking, sorting, choice), the characteristics of the data (quantitative/qualitative, certain/uncertain, complete/incomplete), decision maker preferences (compensatory/non-compensatory), computational constraints, and validation requirements are among the factors that should guide selection.

5 CONCLUSION

This systematic review of 92 MCDM framework studies (2021–2026) shows a dynamic and very active field with following features:

- i. First, methodological clustering around hybrid approaches in which subjective/objective weighting and distance-based, outranking, compromise and utility-based weighting are used.
- ii. Sophisticated uncertainty modelling with higher order fuzzy sets (intuitionistic, Pythagorean, Fermatean, picture, spherical, neutrosophic) and other uncertainty modelling frameworks (gray system, rough set, evidential reasoning).
- iii. Integration of 3 key forms of AI—machine learning for weight learning, deep reinforcement learning for sequential decisions, and large language models for end-to-end MCDM automation.
- iv. Growth in application areas, stimulated by sustainability needs, led by energy, circular economy and green supply chain.
- v. Lack of explicit guidance for method selection, dynamic decision-making and group decisions, validation standards and explainability.

Future Research Directions of Priority

- i. A principled approach to method selection, based on theoretical analysis and empirical benchmarking to link characteristics of the problem with the suitability of the method.
- ii. Standardization of validation procedures, such as benchmark data, test repeatability, and report checklists in MCDM studies.
- iii. Dynamic and adaptive MCDM frameworks—where preferences, criteria and alternatives change over time, which are formally modelled and guaranteed in a theoretic sense.
- iv. Efficient and transparent group decision making mechanisms that can be scaled up to large and heterogeneous groups of stakeholders with conflict resolution.
- v. Explainable AI-MCDM integration ensuring interpretability, trust and ethical alignment in AI-augmented decision support.
- vi. Human-AI Collaborative MCDM Paradigms based on the complementary strengths of human judgment and computational analysis.
- vii. Reusability of domain-specific MCDM ontologies comprising reusable criteria, methods and validation practices for major application areas

The MCDM field is at a turning point: the fusion of traditional operations research rigor and artificial intelligence scalability. Sustained methodological innovation, built upon the principles of decision theory and proven through rigorous, reproducible practice is needed to realize the potential of this convergence.

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